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National Water-Quality Assessment Program
Upper Tennessee River Basin Study Unit

Nitrogen in Streams of the Upper Tennessee River Basin, 1970–93

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INTRODUCTION

In 1994, the U.S. Geological Survey (USGS) began an investigation to assess water-quality conditions in the upper Tennessee River Basin. The study was implemented as part of the National Water-Quality Assessment (NAWQA) Program, which is designed to describe in a nationally consistent manner the status of and trends in the quality of a large representative part of the Nation's surface- and ground-water resources and to relate assessment of status and trends to the natural and human factors that affect the quality of water. When the NAWQA Program is fully implemented, water-assessment investigations will be ongoing in 60 study units across the Nation (Leahy and others, 1990). The general concepts of the NAWQA Program were outlined in a report by Hirsch and others (1988).

The upper Tennessee River Basin study unit (fig. 1) drains an area of about 21,390 square miles (mi^2), which includes the entire drainage of the Tennessee River and its tributaries upstream of the USGS gaging station at Chattanooga, Tennessee. The basin includes parts of four States: Tennessee (11,500 mi^2), North Carolina (5,480 mi^2), Virginia (3,130 mi^2), and Georgia (1,280 mi^2). Four major river systems—Clinch/Powell, Holston, French Broad, and Little Tennessee—make up about 82 percent of the study unit. The basin includes parts of three physiographic provinces—Blue Ridge, Cumberland Plateau, and Valley and Ridge—that are areas of homogeneous climatic, geologic, and biologic characteristics.

Land use in the upper Tennessee River Basin study unit is primarily forest and agriculture. Forest covers about 64 percent of the basin, and agricultural land, which is predominantly pastureland, accounts for about 27 percent of the basin. Most of the agricultural land is located in stream valleys and the more gently rolling areas of the Valley and Ridge Physiographic Province. Urban areas, water bodies, and barren land account for the remainder of the land use in the basin.

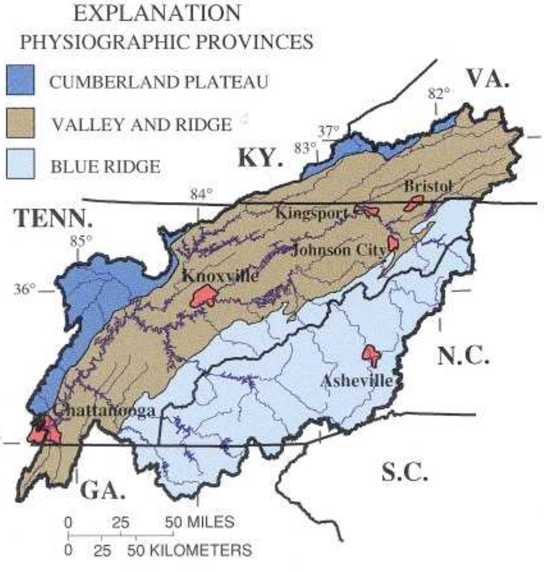

Figure 1. Upper Tennessee River Basin study unit.

Photograph courtesy of the Knoxville Convention and Visitors Bureau

This report presents results of analyses of available data for nitrogen concentrations in streams in the upper Tennessee River Basin. These analyses are part of the retrospective-analysis phase of the study-unit investigation and include the review and analysis of existing water-quality data to provide a historical perspective of water-quality conditions in the study unit. The information was used to assess the available data, develop the initial study design for the NAWQA project, and evaluate priorities for future water-quality research.

Statistical summaries, trend analyses, and stream loads were computed for total nitrogen, total ammonia plus organic nitrogen, and total nitrite plus nitrate ($NO_2^- + NO_3^-$). Concentrations are reported in milligrams per liter as nitrogen, and loads are reported in pounds per day as nitrogen. Data were collected by the USGS, the Tennessee Valley Authority (TVA), and State governmental data-collection agencies in Tennessee, North Carolina, Virginia, and Georgia. All data were retrieved from the U.S. Environmental Protection Agency STORET and the USGS WATSTORE data bases.

Significant Findings

- Highest total nitrogen concentrations associated with agriculture and wastewater-treatment facilities, lowest in forested watersheds.
- Total nitrogen concentrations increased at 12.5 percent and decreased at 14 percent of stations.
- French Broad River and Holston River Basins contributed 40 and 22 percent, respectively, of the total nitrogen load.
- Highest total nitrogen yields were in the French Broad and Pigeon River Basins.

Photograph courtesy of the Tennessee Valley Authority

Photograph courtesy of the University of Tennessee

SOURCES OF NITROGEN

Sources of nitrogen input to streams can be classified as point and nonpoint sources. Point sources are typically piped discharges from wastewater-treatment facilities and from large urban and industrial stormwater systems. Nonpoint sources include stormwater runoff from urban areas, forest, mining, and agricultural lands. Elevated nitrogen concentrations in receiving waters commonly originate from discharges of municipal and industrial waste and urban and agricultural runoff. The application of synthetic fertilizers in urban and agricultural settings or manure from cattle and other farm animals also can result in elevated nitrogen concentrations. Atmospheric inputs resulting from the combustion of fossil fuels and the subsequent release of nitrogen oxides into the air contribute substantial amounts of nitrogen to the environment. Rates of atmospheric deposition of nitrogen in the higher elevations of the southern Appalachian Mountains are among the highest measured in North America (Johnson and Lindberg, 1992).

Nitrogen occurs in the environment in the form of ammonia (NH_3), nitrite (NO_2^-), nitrate (NO_3^-), dissolved molecular nitrogen (N_2), and in various organic compounds. Nitrogen is present in freshwater primarily as NO_3^-, ammonium (NH_4^+), and organic nitrogen. Nitrogen undergoes biological and chemical transformations within the environment. The reduced or organic forms of nitrogen are converted by soil bacteria into nitrite and nitrate, which are used by plants (Cole, 1979).

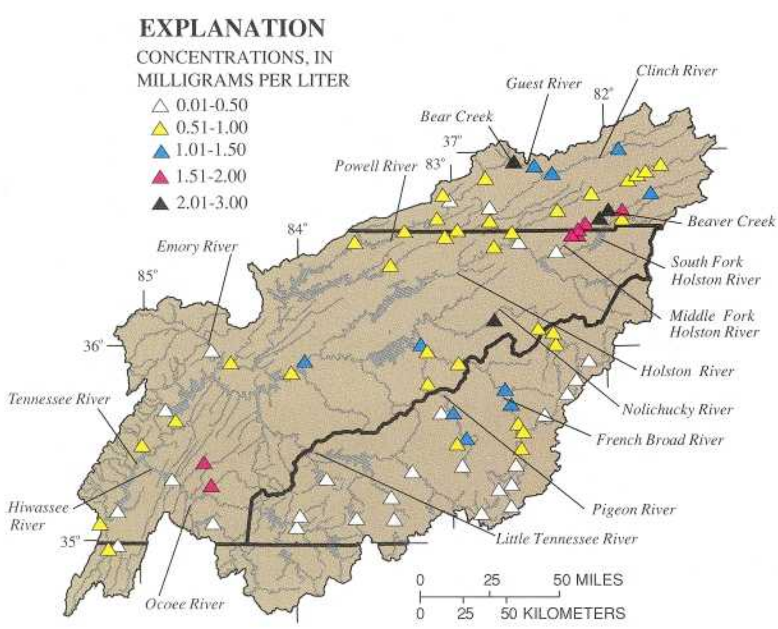

Figure 2. Spatial distribution of median total nitrogen concentrations, 1985-93.

SPATIAL DISTRIBUTION OF NITROGEN CONCENTRATIONS

Concentrations of total nitrogen, total ammonia plus organic nitrogen, and $NO_2^-+NO_3^-$ were assessed quantitatively using data collected at 87 stations in the upper Tennessee River Basin. Median concentrations of total nitrogen from 1985 through 1993 were generally highest for streams in the Middle Fork Holston River Basin near the Tennessee-Virginia State line. Other isolated instances of elevated nitrogen concentrations occurred in the Hiwassee, upper Clinch, and Nolichucky River Basins (fig. 2). Elevated concentrations were associated with agricultural runoff or proximity to wastewater-treatment facilities. During the period, only two stations had concentrations exceeding 5.0 milligrams per liter (mg/L). Maximum concentrations were 7.0 and 12.2 mg/L at stations on Bear Creek and the Pigeon River, respectively. Both stations are located downstream of point-source discharges.

Highest median concentrations of $NO_2^-+NO_3^-$ (1.5 to 2.0 mg/L) were measured in the Middle Fork Holston River Basin, and $NO_2^-+NO_3^-$ accounted for the majority of the elevated total nitrogen concentrations in that basin. Concentrations of total ammonia plus organic nitrogen were generally low (less than 0.5 mg/L) throughout the upper Tennessee River Basin, but total ammonia plus organic nitrogen accounted for the elevated total nitrogen concentrations at the Pigeon River station. However, maximum concentrations of total nitrogen at the Bear Creek station were a result of elevated concentrations of total ammonia plus organic nitrogen and $NO_2^-+NO_3^-$.

TRENDS IN NITROGEN CONCENTRATION

Trend analyses were conducted using the seasonal Kendall statistical test to detect changes in nitrogen concentrations with time. For stations with streamflow data, concentrations were flow adjusted using a method of curve smoothing to remove the variability in the concentration that is associated with streamflow (Helsel, 1993). A significance level (alpha) of 0.05 was considered to show statistical significance of the trend test. Tests were performed for 56 stations in the study unit, and the period of analysis of available data was 1970-93.

Total nitrogen concentration tended to reflect a change in either $NO_2^-+NO_3^-$ or total ammonia plus organic nitrogen. Total nitrogen increased at seven stations and decreased at eight stations in the upper Tennessee River Basin (fig. 3). Of the seven stations with increasing trends, five are located in North Carolina—two stations on the French Broad River and one each on the Little Tennessee River and tributaries to the Hiwassee and Pigeon Rivers. Similar increases also were indicated on the South Fork Holston River and Beaver Creek. Six of the stations with increasing trends of total nitrogen concentration drain

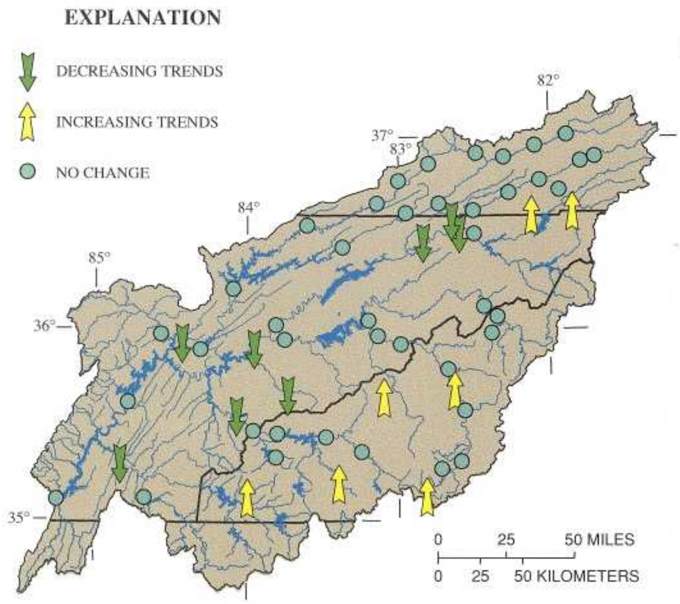

Figure 3. Results of trend analysis for total nitrogen concentrations, 1970-93.

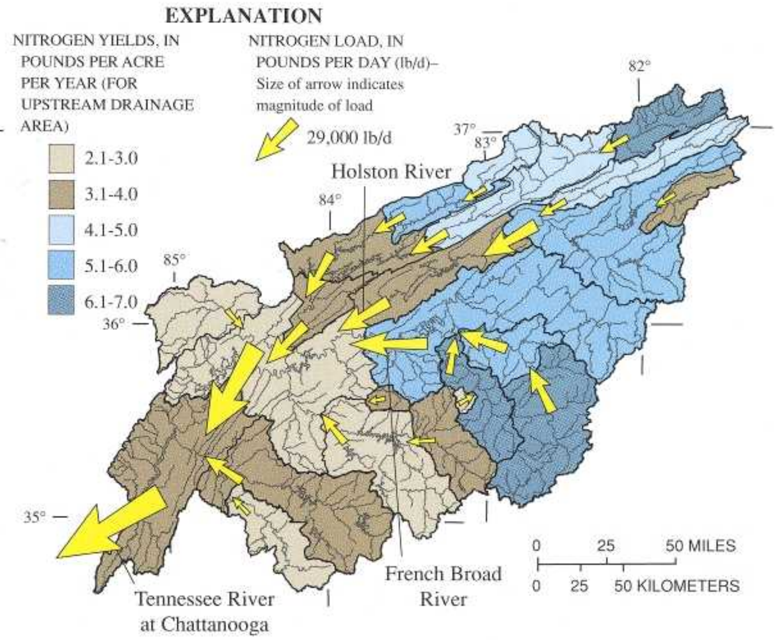

Figure 4. Mean annual total nitrogen loads and yields, 1973-93.

basins with greater than 75-percent forested land. Stations farther downstream in the upper Tennessee River Basin and below major impoundments showed decreasing trends of total nitrogen. The land-use characteristics of the drainages with decreasing total nitrogen concentrations are predominantly mixed forest and agriculture. The average basin size of stations with increasing trends of total nitrogen was 276 mi^2 compared to 2,600 mi^2 for stations with decreasing trends.

Trend analyses indicated that NO_2^-+NO_3^- concentrations increased at 15 stations in the upper Tennessee River Basin, whereas total ammonia plus organic nitrogen concentrations increased at 14 stations in the basin. NO_2^-+NO_3^- concentrations increased primarily at stations in the French Broad and Pigeon River Basins. The drainage areas of these stations include a variety of land uses: forested, agricultural, and urban. Trends of total ammonia plus organic nitrogen increased at three stations on the Clinch River and three stations on the North Fork Holston River, all draining areas consisting largely of agricultural land. Four stations showed a decreasing trend in NO_2^-+NO_3^- concentrations, and total ammonia plus organic nitrogen concentrations decreased at six stations in the upper Tennessee River Basin.

At some stations, the makeup of total nitrogen has changed with time. Ammonia and total organic nitrogen were the dominant nitrogen forms in the 1970's and early 1980's. Gradually, NO_2^- and NO_3^- became more abundant and often were the dominant form of nitrogen. This change is a result of increased control of point-source nutrient inputs, particularly in urban and industrial areas. Total nitrogen removal has proved costly; therefore, nitrogen controls have focused on converting unoxidized forms of nitrogen to less harmful forms such as nitrate (Puckett, 1995).

NITROGEN LOADS AND YIELDS

Annual loads of nitrogen were computed for 23 surface-water stations with reliable streamflow records and corresponding concentration data (fig. 4). Nitrogen loads were estimated using a constituent transport model that uses multiple regression to relate streamflow to the concentration of a water-quality constituent to derive loads (Helsel, 1993).

Nitrogen loads varied among subbasins in the upper Tennessee River Basin study unit and were largely influenced by land use and streamflow conditions. The average annual nitrogen load from the upper Tennessee River Basin at Chattanooga was about 138,000 pounds per day (lb/d) from 1973 through 1993. The French Broad and Holston River Basins, which together drain about 64 percent of the total upper Tennessee River Basin, contributed the greatest amounts of total nitrogen load to the basin, about 40 and 22 percent, respectively (fig. 4).

The reservoirs in the basin often function as a sink for nitrogen, and these reservoirs provide an environment favorable for nitrogen loss or transformation. The fate of nitrogen in reservoirs depends on the physical characteristics of the reservoir (volume, surface area, depth, hydraulic retention time) and its trophic classification (Tennessee Valley Authority, 1991).

Loads of NO_2^-+NO_3^- accounted for more than 60 percent of total nitrogen loads for more than half of the 23 stations. NO_2^-+NO_3^- loads were less than 50 percent of the total nitrogen load for only five stations. The sum of NO_2^-+NO_3^- loads for the six major drainage subbasins in the study area (French Broad, Holston, Clinch, Hiwassee, Little Tennessee, and Emory) totaled 75,400 lb/d annually for 1973 through 1993. Loads of total ammonia plus organic nitrogen were greatest in the French Broad/Nolichucky/Pigeon River Basin.

Nitrogen yields (loads per unit area) are generally a function of land use, basin size, and point-source discharge. Yields of total nitrogen ranged from 2.2 to 7.1 pounds per acre per year [(lb/acre)/yr]. The highest yields occurred in the French Broad and Pigeon River Basins where a combination of agriculture and urban runoff affect surface waters. The French Broad and Pigeon River Basins have a history of water-quality problems associated with industrial point-source discharges. Nitrogen yields were lowest in basins with low percentages of agricultural land use.

Yields of NO_2^-+NO_3^- were highest in the Clinch, Pigeon, and Powell River Basins. NO_2^-+NO_3^- yields were lowest in the Hiwassee, Ocoee, and Emory River Basins and headwater streams. Yields ranged from 5.2 (lb/acre)/yr in the Clinch River Basin to 0.77 (lb/acre)/yr in the Hiwassee River Basin.

Yields of total ammonia plus organic nitrogen were highest in the French Broad River Basin [2.6 to 3.7 (lb/acre)/yr] at four of the five stations with the highest total ammonia plus organic nitrogen yields for the upper Tennessee River Basin for 1973 through 1993. The lowest total ammonia plus organic nitrogen yields were at stations on the Little Tennessee, Ocoee, Clinch, Emory, and South Fork Holston Rivers.

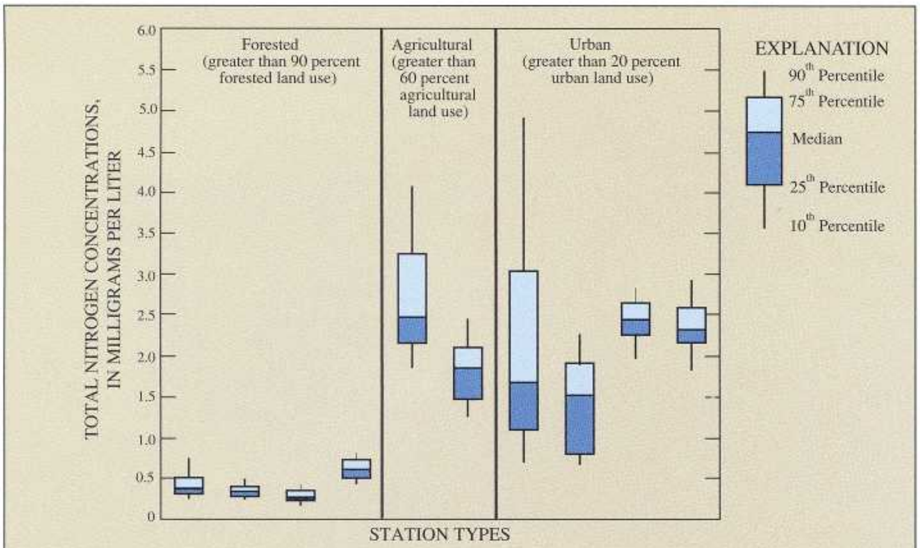

Figure 5. Distribution of total nitrogen concentrations for selected stations grouped by land-use type.

RELATION BETWEEN NITROGEN CONCENTRATION AND LAND USE

The relation between total nitrogen concentrations and the percentage of land use was compared for 87 stations. The relation between nitrogen concentration and land use (forest, agriculture, and urban) is statistically significant at a 0.05 level of significance. Median nitrogen concentrations were compared for selected stations representing different land-use categories (fig. 5). Stations in forested watersheds had the lowest total nitrogen concentrations, whereas stations in agricultural watersheds had the highest concentrations. For urban and mixed land-use stations, concentrations were higher than for forested drainages, but slightly less than concentrations for agricultural drainages. Concentrations were higher with increased agriculture and urban (developed) land use (figs. 5 and 6). Conversely, nitrogen concentrations were lower for stations with higher percentages of forested drainage areas (fig. 6).

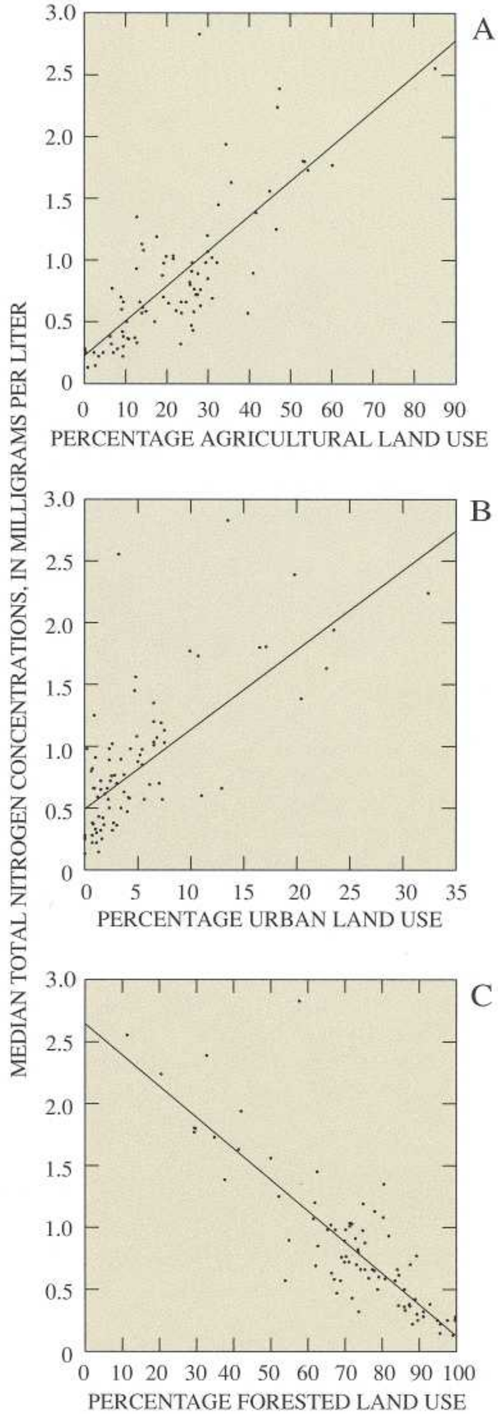

Figure 6. Relation of median total nitrogen concentrations to (A) agricultural land use, (B) urban land use, and (C) forested land use.

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